A VIIRS Ocean Data Simulator

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ABSTRACT

One of the roles of the VIIRS Ocean Science Team (VOST) is to assess the performance of the instrument and scientific processing software that generates ocean color parameters such as normalized water-leaving radiances and chlorophyll. A VIIRS data simulator is being developed to help aid in this work. The simulator will create a sufficient set of simulated Sensor Data Records (SDR) so that the ocean component of the VIIRS processing system can be tested. It will also have the ability to study the impact of instrument artifacts on the derived parameter quality. The simulator will use existing resources available to generate the geolocation information and to transform calibrated radiances to geophysical parameters and visa-versa. In addition, the simulator will be able to introduce land features, cloud fields, and expected VIIRS instrument artifacts. The design of the simulator and its progress will be presented.

Keywords: VIIRS, satellite, ocean, simulator

1. INTRODUCTION

The VIIRS (Visible/Infrared Imaging Radiometer Suite) instrument scheduled to fly aboard the NPOESS Prepratory Project (NPP) satellite contains detectors in the visible and near-infrared range that should have the capability to measure Top Of Atmosphere (TOA) radiances with sufficient accuracy to permit the computation, with suitable processing software, of ocean color quantities such as water-leaving radiances and derived quantities such as chlorophyll-a concentration.[1,2] The success of this task depends on the ability to reliably process the large quantities of data that will be operationally produced and to understand the effects on retrievals of intervening atmospheric, ocean surface, and instrument features. The VIIRS Ocean Science Team (VOST) is developing a VIIRS data simulation system to address these issues. The simulator will help to assess the performance of VIIRS instrument and science software for the generation of ocean color parameters.

The simulator will be integrated into the Ocean Biology Processing Group's (OBPG) Ocean Data Processing System (ODPS) to take advantage of its ability to direct large amounts of computer resources toward the processing of moderate resolution (about 1km) global daily datasets. In addition, the simulator software design will take advantage of the existing processing software used for the processing of other ocean color instrument data such as SeaWiFS on OrbView-2 and MODIS on Aqua and Terra. This will have 2 advantages: 1 - the simulator will require less new development due to the use of existing functions, and 2 - the processing will share a common algorithmic basis with other ocean color processing.

In this paper, the design of the VIIRS data simulator is discussed. The overall flow of the simulator will be shown followed by a more detailed discussion of the elements of the simulator. Examples of the input data and the resulting simulated VIIRS radiances will be shown. Future enhancements to the simulator will also be discussed.

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2. OVERALL DESIGN OF THE VIIRS SIMULATOR

The processing of NPP data will be performed by the Interface Data Processing Segment (IDPS) at the National Environmental Satellite, Data, and Information Service (NESDIS). VIIRS ocean data processing consists of a sequence of steps that take the data from the raw satellite data to commonly mapped scientific qualtities. First, the satellite data is placed in a Raw Data Record (RDR) format - which contains the instrument packet data. Radiances in raw counts make up the dataset at this point. The next level is the Sensor Data Record (SDR) which has the counts converted into actual radiance at the TOA. This data is then processed into Environmental Data Records (EDR), containing the data of interest to the ocean scientists such as normalized water-leaving radiances and chlorophyll-a. EDR data can then be mapped to a common projection, allowing it to be time averaged.

Figure 1 shows the major elements of the VIIRS simulator. Currently, the simulator creates VIIRS Sensor Data Records (SDR) for the moderate resolution (M) bands used for ocean color processing. The SDR contains the calibrated TOA radiances from the VIIRS instrument, navigation information, data quality information and identifying metadata. The simulator starts with a realistic VIIRS orbit description, and a source of realistic water-leaving radiances and aerosol characteristics, preferably ocean color data from other ocean color instruments. The steps in the simulation process are numbered (in Fig. 1) in the order in which they are performed in the course of a normal simulation. The steps are:

1. **VIIRS viewing geometry simulation.** Use a simulated orbit to generate the VIIRS-viewed geometry, including earth latitude and longitude, solar and satellite zenith and azimuth angles for all those points. The information is generated for the standard length VIIRS granule of 48 scans or 768 lines by 3200 samples made by the 16 detectors for one M-band.

2. **Ocean color scene simulation.** Use the general geographic range of the VIIRS granule(s) to select other ocean color satellite data, to use in generating a special level-3 base scene containing all the required parameters to use in the simulation. This file can be compiled from many days of of data to achieve full geographic coverage.

3. **Create a VIIRS SDR without radiances.** Create a simulated VIIRS SDR file based on the VIIRS-viewed geometry. The resulting file will be in the format of a VIIRS SDR file but it will only contain placeholder top of atmosphere radiances.

4. **Select ocean color data at VIIRS locations.** Extract parameters from the Level-3 base scene and located at the VIIRS geographical locations. This makes a set of ocean surface values of radiance and aerosol information as VIIRS would see them.

5. **Simulate TOA radiances as seen by VIIRS.** Re-construct the top of atmosphere radiances by running the OBPG level-2 processing program: l2gen, in the inverse mode. Atmospheric components seen with the VIIRS geometry are added back to the target file water-leaving radiances to make the TOA radiances.

6. **Insert TOA radiances into simulated SDR.** Replace nominal TOA radiances in the VIIRS SDR file with the simulated TOA radiances. This can either be done directly, or other features, such as clouds and instrument artifacts can be added.

3. DETAIL OF STEPS IN CREATING THE SIMULATED SDR

The VIIRS simulation process takes a set of observed water-leaving radiances from the ocean surface combined with an estimate of the overlying atmosphere properties and simulates the radiances as seen by the VIIRS instrument at the top of the atmosphere. The first Two steps of the simulation define the locations and view geometry seen by VIIRS and assemble the required simulated surface and atmospheric information.

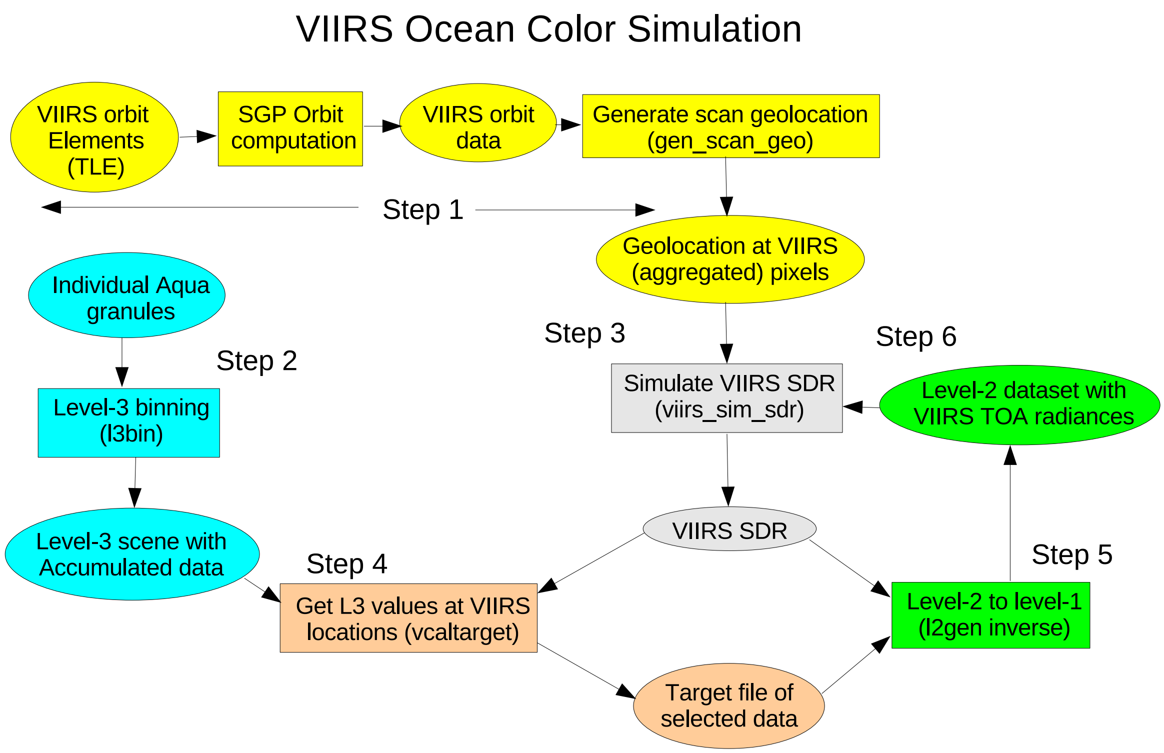

Figure 1. Flow chart depicting the major processing steps in the VIIRS data simulation. The numbers show the sequence of the simulation steps.

3.1 VIIRS Viewing Geometry Simulation

The simulation begins with the creation of a set of location and view angle information for every pixel viewed by the VIIRS instrument (step 1 in Fig 1). A simulated orbit for NPP is generated from two-line element (TLE) sets, using the SGP4 program acquired from U.S. Project Spacetrack. The SGP4 model includes orbit perturbations to fourth order and also atmospheric drag. It allows orbit vectors to be output at any desired interval. For purposes of the VIIRS simulation, the vectors were generated at 1-minute intervals. The SGP4 vectors are in a true-equator, mean-equinox (TEME) reference frame. Prior to use in the simulation, they are transformed to the Earth-centered Earth-fixed (ECEF) frame. This involves rotating the vectors around the Earth's North Pole by the Greenwich Hour Angle (GHA), and also adjusting the velocity vectors for the Earth rotation rate.[3]

The NPP orbit is then used along with a nominal instrument attitude to derive the latitude and longitude of the aggregated VIIRS sample centers[2] and the satellite and solar zenith and azimuth angles for these samples. The gen_scan_geo program interpolates the orbit information to the VIIRS scan rate of 1 scan per 1.7864 seconds. The sensor orientation is determined at each scan time using the orbit information and the nominal attitude. The VIIRS scan geometry, the sensor orientation, and an earth model are them used to determine the latitudes and longitudes of the scan pixels and the sensor zenith and azimuth angles. A rederence Sun vector, determined by the scan time, is used to determine the solar zenith and azimuth angles at the locations. The locations and view angles are placed in a temporary HDF-5 file.

3.2 Ocean Color Scene Simulation

A scene of ocean and atmospheric properties at the ocean surface is generated based on ocean color data from other instruments. Ocean color data from an ocean color instrument with similar frequency bands is used for this purpose. Water-leaving radiances from MODIS Aqua which are at wavelengths very close to the visible and infrared wavelengths of VIIRS are chosen (see Table 1). Aerosol optical thickness and aerosol type— as indicated by the Angstrom coefficient are included to characterize the aerosol in the atmosphere.

Individual Aqua scenes posess neither the proper overlap with a VIIRS swath nor do they contain an un-broken field of water-leaving radiances due to cloud and glint contamination of the Aqua data. The ocean color data collection step takes the required parameters and accumulates them over an 8-day time period to create a nearly un-broken scene of normalized water-leaving radiance and aerosol parameters of aerosol optical depth and Angstrom coefficient. This is performed using the available ODPS level-3 binning process: l3bin. A global binning of Aqua data will be produced to make running averaged daily scenes of surface and atmospheric parameters to be used in the simulation.

3.3 Create a VIIRS SDR without Radiances

The previous 2 steps have created the scene and the way the VIIRS instrument looks at that scene. This step (step 3 in Fig 1) creates the VIIRS SDR that conforms to the format specified in the NPOESS Common Data Format Control Book (CDFCB).[4,5] The SDR is actually a set of files consisting of a geolocation file and a file for each of the seven M-bands used for ocean color processing (See the bands in Table 1). The VIIRS SDR dataset simulator program, viirs_sim_sdr, creates these datasets containing all the identifying metadata and quality information. The geolocation and view geometry are extracted from the geolocation file and are placed in the proper datasets. A temporary set of placeholder, band-dependent constant TOA radiances, based on typical TOA radiances, are placed in the appropriate M-band SDR file. The SDR is created in HDF 5 format as described by the CDFCB.

3.4 Select Ocean Color Data at VIIRS Locations

The simulated surface scene, created in step 2 can now be sampled at the VIIRS sample locations. This step is done by the existing vcaltarget program (step 4 in Fig 1). vcaltarget was enhanced to use a VIIRS SDR as a source for location information. vcaltarget uses the latitude and longitude information from the VIIRS SDR to select the water-leaving radiances and aerosol information at those points in the surface scene. Binary target files of this information are then created. vcaltarget can be adjusted to select only the Level-3 data that is in perscribed chlorophyll and aerosol optical thickness limits.

3.5 Simulate TOA Radiances as seen by VIIRS

The binary files from vcaltarget created in step 4 are converted into TOA radiances in this step (step 5 in Fig 1). The standard OBPG Level-2 processing program, l2gen[6] is used for this step. Normally, l2gen is used to remove the atmospheric influences from TOA radiances to create water-leaving radiances and aerosol properties. For the SDR simulation, l2gen is run in the inverse mode that takes the water-leaving radiances in the target file and adds atmospheric radiance contributions as seen by the VIIRS instrument for the view geometry specified in the SDR file. The inversion process uses the same software and principles as those used for the OBPG to perform the vicarious calibration of other ocean color instruments.[7] The normalized water-leaving radiances are converted into water-leaving radiances as seen by the VIIRS instrument. The aerosol radiance, determined by the scene aerosol optical depth and angstrom coefficient is added to the water-leaving radiances. Rayleigh radiances are then added and the effects of ozone absorption are accounted for. This results in a TOA radiance set. The l2gen program places the TOA radiances in it's Level-2 format dataset. The existing l2gen program was enhanced to work with the VIIRS SDR format.

Table 1. VIIRS bands and the corresponding MODIS Aqua bands.

VIIRS band	λ (nm.)	Aqua band	λ (nm.)
M1	412	8	412
M2	445	9	443
M3	488	10	488
M4	555	12	551
M5	672	13	667
M6	746	15	748
M7	865	16	869

3.6 Insertion of TOA Radiances into Simulated VIIRS SDR

The last step of the simulation (step 6 in Fig 1), places the TOA radiances into the SDR file. This is done by running the viirs_sim_sdr program. This step is similar to step 3, but in addition to inserting the geolocation information, the file of TOA radiances taken from the level-2 file is also inserted into the simulated SDR. The transfer of the simulated radiances was designed so that radiance values at any sample could be modified using the surrounding field of radiance values. The modifications will include the addition of simulated land and cloud radiances. The ideal TOA radiances can be further modified by the expected effects of the VIIRS instrument artifacts.

4. STATUS AND SIMULATION EXAMPLES

The VIIRS simulator has been in development since the Fall of 2008. At this time, it can do all the basic steps described in section 3 except for adding the cloud, land, and instrument artifacts. The upgraded software, new tables, and new software are being integrated into the ODPS for more testing and larger scale simulation runs.

In this section, an example of the input and resulting simulated datasets is shown. The example shown here is for a simulated NPP orbit on 1 January, 2006.

Fig. 2 shows the subpoint of the simulated NPP orbit for the entire day projected on the earth as the curve. A simulated VIIRS granule of data was selected starting at 0000 GMT. The coverage of this granule is shown as the black rectangle in Fig. 2. Fig. 3 focuses only upon the region covered by the simulated granule. For purposes of clarity, only every 16th pixel along-scan is plotted. Also, only the first and last detector locations (out of the 16 detectors) have been plotted for the 48 scans that make up this granule. The VIIRS aggregation zones can be seen as the change in point density from the scene center (with every 3 raw samples aggregated) to the edge (shifting from 2 sample aggregation to using every sample). The along-track spreading of the samples (the bow tie effect) can also be seen occuring at the scan edge. The region covered by this granule is almost all ocean except for the island of Kiritimati at 2 degrees latitude and 157.5 degrees longitude.

MODIS Aqua granules for the time period of 1 - 9 January 2006 were accumulated by the l3bin program for this region to create the base scene of normalized water-leaving radiances and atmospheric properties. The normalized water-leaving radiance distribution in the blue wavelength band at 443 nm. from this base scene is shown in Fig. 4. The central region of the scene has better coverage because only MODIS granules that actually covered the VIIRS region were closen to make the scene and fewer MODIS granules (and more data gaps) made up regions outside the VIIRS granule coverage. A rough band of lower (about 0.7 mW cm^{-2} um^{-1} sr^{-1}) radiance can be seen along the equator, corresponding to higher chlorophyll concentrations.

Radiances and atmospheric data from this scene were sampled at the VIIRS simulated locations, propagated to the TOA and placed in the simulated VIIRS SDR dataset. We processed that dataset through l2gen to get back the normalized water-leaving radiances and chlorophyll-a. Note that the actual VIIRS ocean

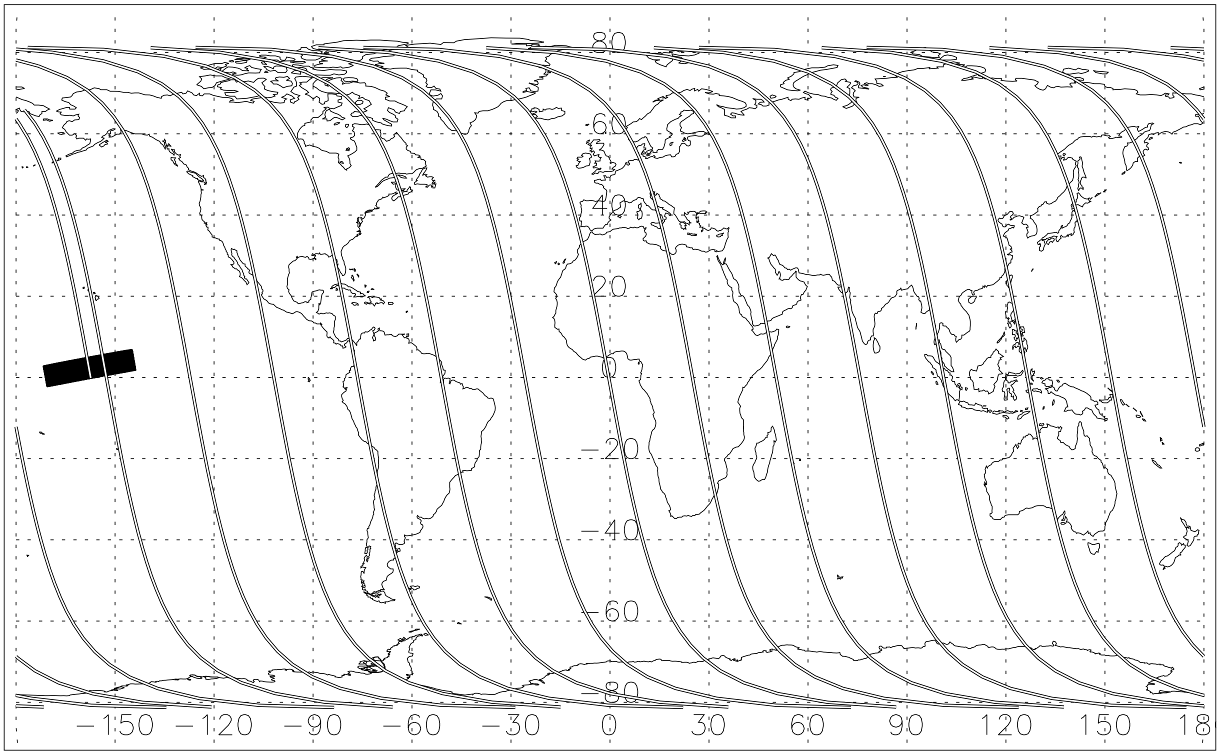

Figure 2. Plot of the VIIRS simulated orbit for 1 day. The box in the Pacific is the coverage of the simulated granule used in this example.

processing of IDPS will use different software and algorithms. Fig. 5 shows an image of the normalized water-leaving radiance at 445 nm. The image is mapped into the same cylindrical projection as in Fig. 4. Features in the radiances and the chlorophyll were preserved through the simulation process. Visually, the retrieved radiance field appears to show lower values in the Western portion of the scene as compared to the base scene and may indicate a difference in processing controls used in some of the simulation or retrieval steps. The numerical values in these datasets still need to be compared in more detail. Some coverage near the scan edge appears to have been lost in the simulation process.

Further tests need to be done to understand the source of the lost samples in the simulation, to check the proper processing controls, and to check the fidelity of the entire simulation process but the basic process is working well.

5. FUTURE ENHANCEMENTS

5.1 Tables derived from VIIRS Characterization

The process of reconstructing the TOA radiances from the surface values requires the knowlege of several atmospheric effects which are computred from the VIIRS Relative Spectral Response (RSR). When the VIIRS M-band RSR is determined in thermal vacuum characterization, the following tables can be computed and used instead of the current MODIS Aqua stand-in tables:

- Tables for Rayleigh radiance
- Aerosol model radiances

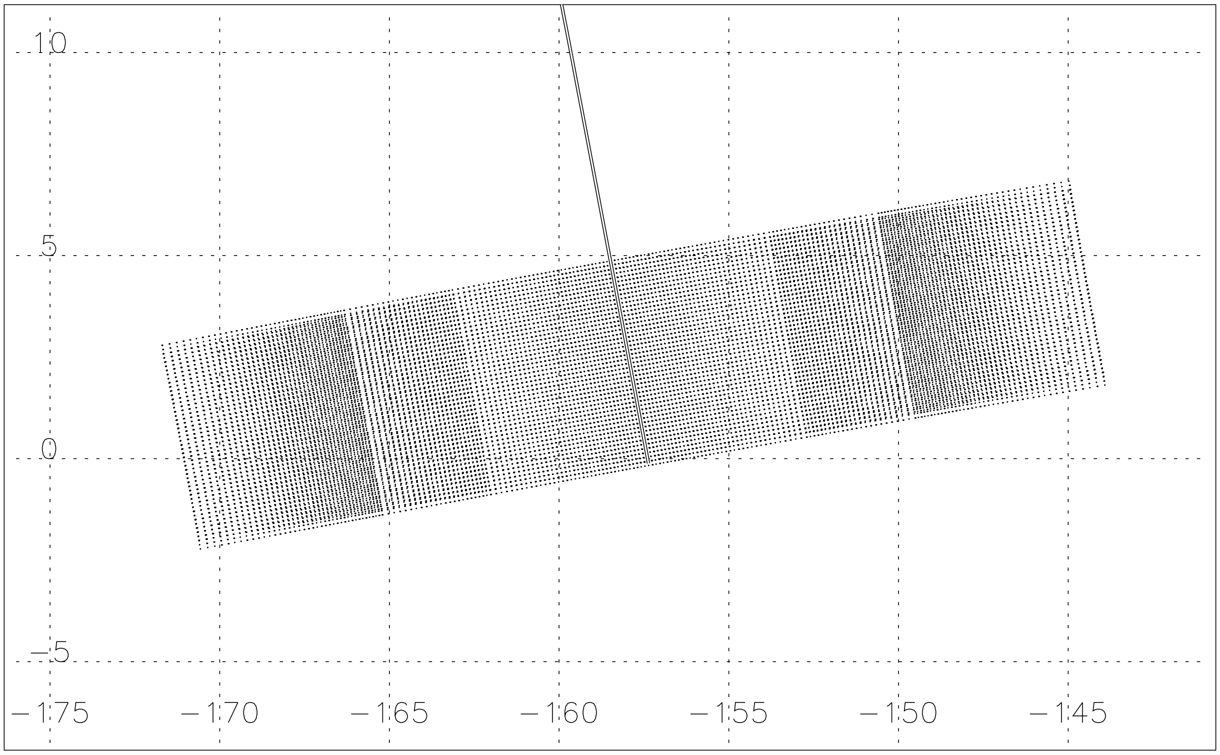

Figure 3. Plot of the VIIRS simulated granlue coverage, using sub-sampled data point locations and the orbit ground track.

- Band centers for the M bands
- Ozone absorption coefficients
- NO2 absorption coefficients
- Extraterrestrial solar irradiances
- CO2 transmittances
- H2O absorption coefficients
- Whitecap coefficients
- Clear water absorption coefficients

5.2 Geophysical Influences

VIIRS ocean pixel processing is affected by land in close proximity. The relatively bright land radiances will contaminate the ocean radiances due to stray light in the instrument. The simulation of land radiances can be done by collecting cloud-free SeaWiFS radiances over land. The SeaWiFS radiances are preferred to MODIS radiances because SeaWiFS does not saturate at the high land radiance values. A suitable land scene can be accumulated using cloud-free pixels from several days of data. This radiance is then used to replace the (probably 0 valued) simulated TOA radiances during the SDR simulation step in program viirs_sim_sdr (step 6 in Fig 1).

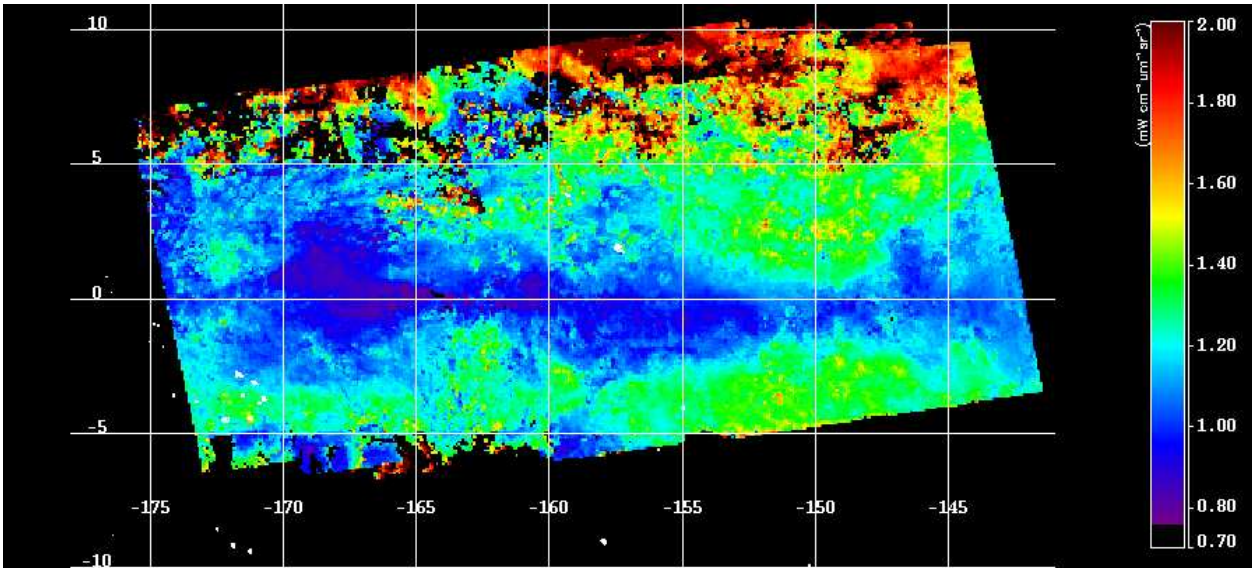

Figure 4. Image of the water-leaving radiance at 443 nm (nLw_443) from the 8-day accumulated MODIS Aqua scene that was used to create the simulated VIIRS dataset. The radiance in the image is scaled linearly from 0.7 - 2. mW cm^{-2} um^{-1} sr^{-1}.

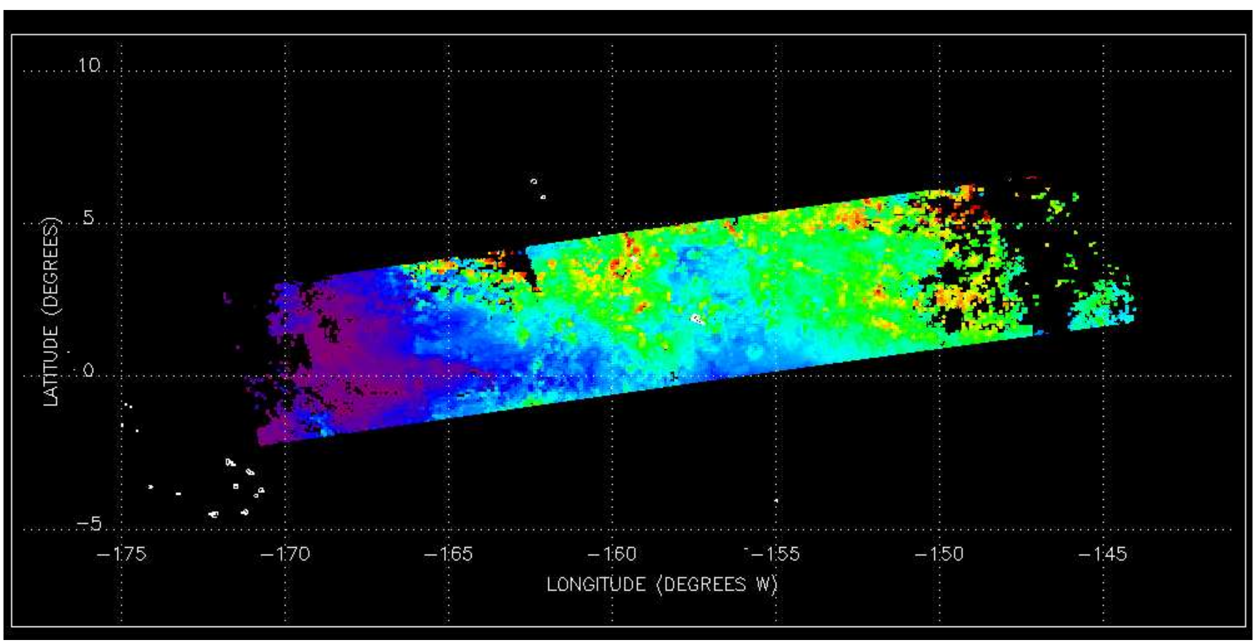

Figure 5. Image of the water-leaving radiance at 443 nm (nLw_443) processed from the simulated VIIRS dataset. The radiance in the image is scaled linearly from 0.7 - 2. mW cm^{-2} um^{-1} sr^{-1}.

In a similar way, cloud fields can be determined in the SeaWiFS data (or assumed to be white in Aqua data). The creation of a cloud field will be more difficult than the land radiances because the clouds move from day-to-day. Clouds from different granules of data will have to be reconciled to make a physically reasonable cloud scene. Cloud radiances can then replace the land or ocean TOA radiances in the simulated SDR.

Sun glint is one of the effects that is included as the surface radiances are propagated to the TOA (by l2gen) and should not have to be added by the SDR simulator step. Moderate glint is correctable in the level-2 processing but severe glint cannot be acurately corrected and must be excluded in the retrieved radiances. The performance of the VIIRS retrieval can be tested for these glint conditions.

5.3 Instrument Influences

The VIIRS detectors are not ideal and the signal at one detector will be dependent on the radiances in the surrounding areas. Near field and far field stray light will occur when light scattered of elements in the optical path are directed into a detector. Crosstalk occurs when light impinging on one detector is partially directed into another adjacent detector. In VIIRS, this effect has been shown to be significantly affected by the polarization of the incoming light. When the scattered light originates from another band's filter, the effect resembles out-of-band radiance (except that it is dependent upon the strength of the radiance in the scatterer instead of the receiver detector). Electronic cross talk has a similar effect, but its source is the leaking of electrical signals between electronic elements of different detectors.

The linearity of the VIIRS detector response to radiance is affected by broad non-linearities of the detector response and by localized non-linear effects that occur when the M-band detectors transition from high- to low-gain state.[8] Quantization of the signal by the analog to digital radiance convesion, especially above the gain transition, will add uncertainty to the radiances.

These effects are being characterized for NPP VIIRS during pre-launch testing. The VIIRS SDR simulator will be able to add these effects to the simulated radiances to guage their impact upon retrievals versus retrievals made for an uncontaminated scene. The success of corrections for these effects can also be investigated.

5.4 Simulating the VIIRS Raw Data Record

The VIIRS simulator may be expanded to convert the SDR dataset into the un-calibrated Raw Data Record (RDR) format files. This would help to test the RDR to SDR portion of the processing software. It can verify that the processing software is working correctly in the calibration algorithm and metadata insertion functions. Performance of the software with large data volumes could also be tested.

5.5 VIIRS SDR Software Improvements

There are some small details about the simulation of a VIIRS SDR that also need to be included. A portion of the radiance data that overlaps in successive scans due to the bow tie effect is normally not included in the VIIRS data. This effect still needs to be added to the SDR simulator. The simulator will also need to be improved to have more realistic QC data included in response to simulated data problems.

6. SUMMARY

The VIIRS simulator is now being readied for installation in the OBPG processing system, which has the capability to quickly run the simulation and generate large amounts of simulated VIIRS data. This will enable the testing of the software performance under the conditions of large data volumes. When the enhancements of land, cloud, and instrument effects are added, the simulator can also be used to test the impact of geophysical and instrument influences on the retriebvals made by either the OBPG software or the IDPS software.

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